

Measurement of D^0 decays to $K_L^0\pi^0$ and $K_S^0\pi^0$ at Belle

The Belle Collaboration

Abstract

We present a preliminary measurement of the ratio of D^0 decay rates into $K_L^0\pi^0$ and $K_S^0\pi^0$ final states. This ratio can be used to disentangle the Cabibbo favored $D^0 \rightarrow \bar{K}^0\pi^0$ and doubly Cabibbo suppressed $D^0 \rightarrow K^0\pi^0$ amplitudes, and contributes to the important goal of constraining the strong phase $\delta_{K\pi}$ between $D^0 \rightarrow K^-\pi^+$ and $D^0 \rightarrow K^+\pi^-$. The measurement is based on a large data set accumulated by the Belle detector at the KEKB e^+e^- collider, with K_L^0 candidates reconstructed using hadronic clusters in the KLM (K_L^0 and μ identification system), together with a D^0 mass constraint and D^* tag.

PACS numbers: 13.25.Ft

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I. INTRODUCTION

The search for $D^0 - \bar{D}^0$ mixing has long been one of the most interesting projects in charm physics. Recent publications by the FOCUS [1] and CLEO [2] collaborations have stimulated a series of new measurements, including an updated y_{CP} measurement by the Belle collaboration [3], reported at the summer conferences. However, the experimental situation is still not clear.

An important quantity in the interpretation of $D^0 - \bar{D}^0$ mixing results is the phase difference $\delta_{K\pi}$ between the Cabibbo favored (CF) and doubly Cabibbo suppressed (DCS) neutral D meson decays. As has been shown in [4], new information on $\delta_{K\pi}$ may be obtained by measuring the asymmetry between the decay rates of D^0 into $K_S^0\pi^0$ and $K_L^0\pi^0$, where the effect may be as large as $\mathcal{O}(\tan^2\theta_c)$, i.e. at the 5% level.

In this paper we present the first measurement of the $D^0 \rightarrow K_L^0\pi^0/D^0 \rightarrow K_S^0\pi^0$ decay rate asymmetry, using the Belle detector at the KEKB e^+e^- collider. In order to cancel out most of the systematic effects of the detector, we extract the K_L^0/K_S^0 relative detection efficiency from the ratio of $K_L^0\pi^+\pi^-$ and $K_S^0\pi^+\pi^-$ modes via the decay $D^0 \rightarrow K^{*-}\pi^+$. The presence of $K^{*-} \rightarrow K^0\pi^-$ in the decay chain ensures equal rates of K_L^0 and K_S^0 in this case.

Throughout this paper, the inclusion of CP-conjugate processes is implied. In particular, we combine $D^0 \rightarrow K_L^0\pi^0$ with $\bar{D}^0 \rightarrow K_L^0\pi^0$, and so on. We thus treat the K_L^0 and K_S^0 as CP-eigenstates (the error is negligible) and assume that direct CP violation in $D \rightarrow \bar{K}\pi$ and $K\pi$ decays, if present, may be ignored at our present sensitivity.

II. K_L^0 RECONSTRUCTION TECHNIQUE

The key point in the analysis of final states containing K_L^0 is the reconstruction of its momentum. The technique presented below makes use of the KLM (K_L^0 and μ identification) subsystem of the Belle detector [5], which consists of several layers of iron absorber interspaced with resistive plate chambers. The system enables one to reconstruct muon tracks as well as hadronic showers. Those showers which do not have a matching charged track are assumed to be produced by K_L^0 , with the position of the shower giving information about the flight direction of the K_L^0 . The direction resolution is improved if the K_L^0 deposits energy in the electromagnetic calorimeter in front of the KLM, in which case the position of the calorimeter cluster is used to determine the K_L^0 flight direction.

To extract the *magnitude* of the K_L^0 momentum one needs to employ additional constraints. In particular to reconstruct D^0 decays into $K_L^0 X$ where X is a fully reconstructed system, one can apply a D^0 mass constraint and solve the resulting 4-momentum equation with respect to the magnitude of the K_L^0 momentum, and then exploit the $D^* \rightarrow D^0\pi$ decay to tag the signal.

To monitor the performance of the method we utilize the same D^0 decay modes but with K_S^0 instead of K_L^0 in the final state. We use the K_S^0 flight direction reconstructed by its decay into $\pi^+\pi^-$, and then apply the same procedure as for K_L^0 : henceforth such K_S^0 are referred to as \widetilde{K}_L^0 (pseudo K_L^0).

Since the equation for the magnitude of the K_L^0 momentum is quadratic there may be up to two solutions. However one of those, even if present, is non-physical in more than 90% of events. For simplicity, in this analysis we use only the one with the larger momentum.

III. DATA SET AND EVENT SELECTION

The data sample used for this analysis amounts in total to an integrated luminosity of 23.6 fb^{-1} .

We select D^* candidates with reconstructed scaled momentum $x_p > 0.6$, which rejects D^* from B -meson decays and suppresses the combinatoric background. In addition to the standard reconstruction procedure for π^\pm , π^0 , and K_S^0 , the latter are required to satisfy the following quality criteria:

- the $K_S^0 \rightarrow \pi^+\pi^-$ vertex should be separated from the interaction point in the plane perpendicular to the beam axis by more than $500 \text{ }\mu\text{m}$;
- the distance along the beam axis between the π^\pm tracks at the K_S^0 vertex must be less than 1 cm ;
- the cosine of the angle between the assumed K_S^0 flight path from the interaction point to the decay vertex and the reconstructed K_S^0 momentum in the transverse projection with respect to the beam must be more than 0.95 .

When reconstructing K_L^0 , there is a potential background due to KLM clusters caused by unreconstructed charged particles, in particular when these particles do not originate from the interaction region (e.g. K and π decays in flight). To reject such cases we veto any KLM cluster matched to a calorimeter cluster with an energy between 0.15 and 0.3 GeV , corresponding to minimum ionization.

The dominant part of the background is due to the pickup of arbitrary soft pions when forming a D^0 candidate. A characteristic feature of such combinations is that the D^0 mass is accommodated by assigning a large momentum to the K^0 , which then accounts for most of the D^0 momentum. Therefore the K^0 flight angle with respect to the D^0 boost (hereafter θ_{DK}) for this background tends to peak in the forward direction (Fig. 1b) while for the signal the underlying distribution is isotropic, with a slight tilt to the forward direction in the measured distribution (Fig. 1a) due to detector efficiency.

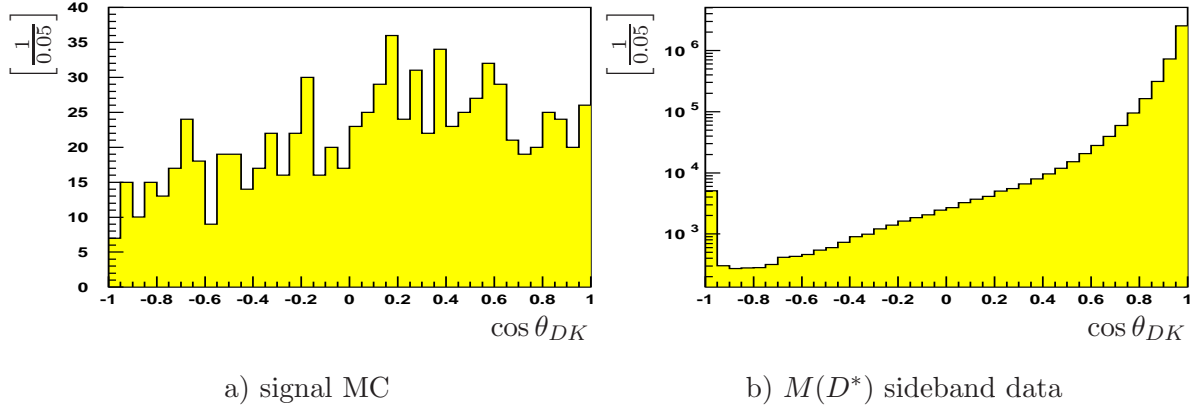


FIG. 1: K^0 flight angle with respect to the D^0 boost for $D^0 \rightarrow \widetilde{K}_L^0 \pi^0$

The sharp peak around $\cos \theta_{DK} = -1$ is due to the degenerate case when a random π^0 or $\pi^+\pi^-$ system can form a “good” D^0 with a K^0 (almost) at rest in the lab: to exclude these cases,

we require $\cos\theta_{DK} > -0.95$. The upper cut on this quantity needs optimization which has been performed using signal MC and data in the $M(D^*)$ sideband: we require $\cos\theta_{DK} < 0.2$ for all four modes.

The invariant mass of the $K^0\pi^-$ combination in the $K^0\pi^+\pi^-$ mode is required to lie within 50 MeV/ c^2 of the nominal $K^*(892)$ mass. In addition the invariant mass of the $\pi^+\pi^-$ pair is required to be less than 0.7 GeV/ c^2 to make the signal and the control modes kinematically similar, and to suppress the contribution from $K^0\rho$ decays.

Since the kinematics in the K_L^0 and the corresponding K_S^0 modes is the same we can use the fully controlled $K_S^0\pi^0$ and $K_S^0\pi\pi$ modes to select a region in the K^0 lab momentum where the efficiency of the kinematical cuts, which is independent of the K^0 flavor, is the same (see Fig. 2). Hence we can average over this region and all the efficiencies including that of K_L^0 reconstruction cancel out. We select the K^0 lab momentum range from 0.6 GeV/ c to 2.5 GeV/ c for this analysis.

IV. DETERMINATION OF K_L^0 AND K_S^0 RATE RATIO

The resulting D^* mass plots for the four D^0 decay modes under study are shown in Figure 3. For the modes including K_S^0 these are mass difference plots in the traditional reconstruction with a very loose cut on the D^0 mass (within 100 MeV from the nominal value). The distributions for the K_S^0 modes have been fit to a sum of two gaussians representing the signal and its tails and a first order polynomial multiplied by a square root threshold factor to describe the background, while for the signal in the K_L^0 modes a single gaussian was used. The central value of all the gaussians was fixed at the nominal charged D^* mass; all other parameters were allowed to float.

The yields obtained from the fit are

$$\begin{aligned} N(K_S^0\pi^0) &= 4715 \pm 91, \\ N(K_L^0\pi^0) &= 1839 \pm 101, \\ N((K_S^0\pi)\pi) &= 2524 \pm 77, \\ N((K_L^0\pi)\pi) &= 1119 \pm 84. \end{aligned}$$

They are used to calculate the ratio of branching fractions of $D^0 \rightarrow K_L^0\pi^0$ and $D^0 \rightarrow K_S^0\pi^0$

$$\frac{\mathcal{B}(D^0 \rightarrow K_L^0\pi^0)}{\mathcal{B}(D^0 \rightarrow K_S^0\pi^0)} = \frac{N(K_L^0\pi^0)/N(K_S^0\pi^0)}{N((K_L^0\pi)\pi)/N((K_S^0\pi)\pi)} = 0.88 \pm 0.09(\text{stat})$$

V. EVALUATION OF SYSTEMATIC ERRORS

Due to the similarities in the behavior of the signal $K^0\pi^0$ and control $(K^0\pi)\pi$ modes most of the systematic errors cancel out. However some steps in the analysis are different and thus may have different systematic effect on the result.

We consider the following potential sources of systematic errors which may not cancel:

- the effect of the residual difference in K_L^0 lab momentum spectra, which can lead to a bias in the result if the K_L^0 reconstruction efficiency strongly depends on momentum;
- systematic errors due to the imperfect fitting function.

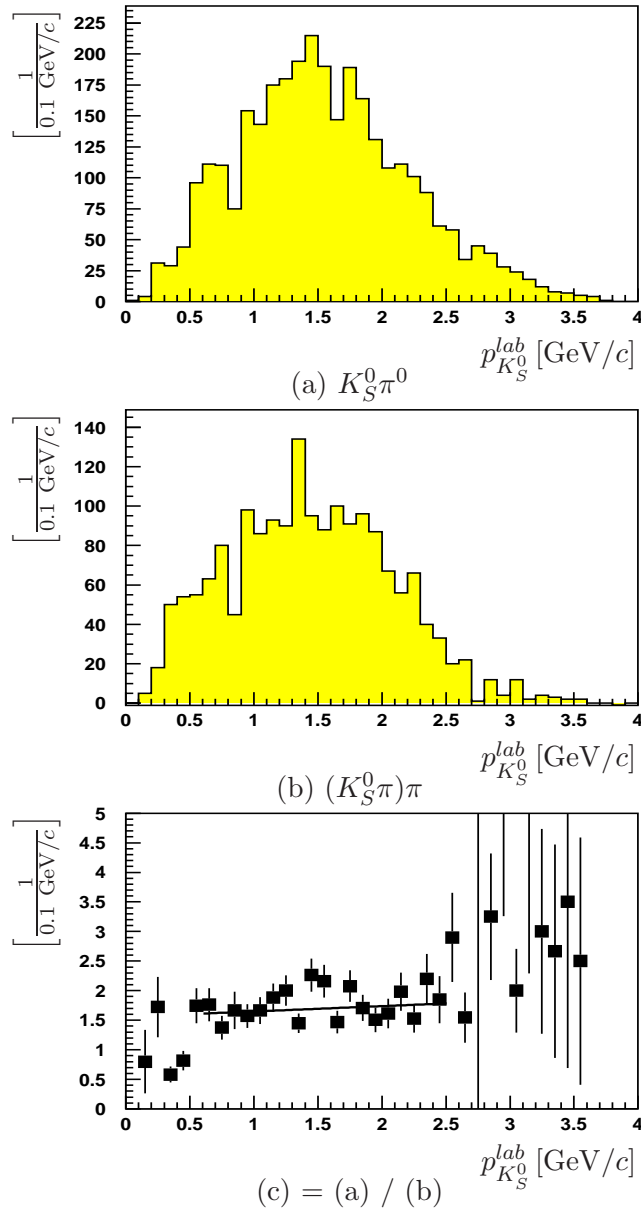


FIG. 2: K^0 lab momentum spectra for (a) $K_S^0 \pi^0$ and (b) $(K_S^0 \pi) \pi$; (c) shows the ratio of (a) to (b) as a function of momentum.

In order to estimate the bias induced by the residual difference in K_L^0 lab momentum spectra, an artificial momentum-dependent “efficiency” was introduced in $K_S^0 \pi^0$ and $(K_S^0 \pi) \pi$ modes by applying a weight depending on the K_S^0 lab momentum. The weight changed linearly from 0 at 0.6 GeV/c to 1 at 2.5 GeV/c , representing the worst possible case. The resulting change in the ratio of yields was less than 3%.

Systematic errors arising from imperfections of the fitting model were evaluated by varying the functions describing the signal and the background: in particular we employed a double gaussian to describe the signal in K_L^0 modes as well as in K_S^0 , and a second order polynomial multiplied by the square root threshold factor to fit the background. The yield ratio remained stable within 6%

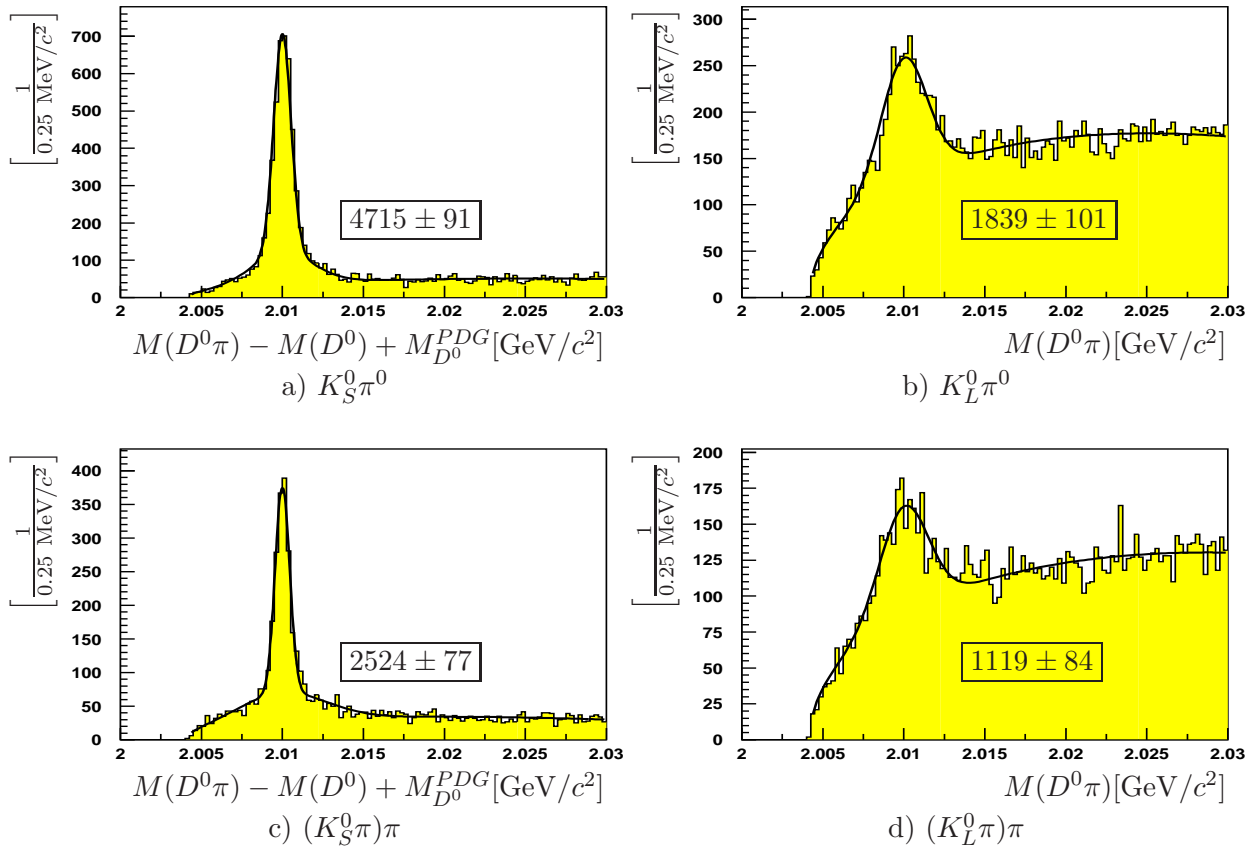


FIG. 3: D^* mass plots for the specified D^0 decay modes

under all variations of the fitting model that were studied.

In addition, the stability of the fit against variation of the background level was studied by simultaneously varying the cut on $\cos\theta_{DK}$ in all the four modes: we estimate the error on the yield ratio due to this source to be 8%.

Adding these sources of error in quadrature, we estimate the total systematic error to be 10%. Since this error is dominated by the difficulty of parametrizing the background, there is potential for improvement if the shape of the background can be simplified. One technique currently being studied is the replacement of the $M(D^0)$ constraint with a constraint on $M^2(D^*) - M^2(D^0)$ when forming the K_L^0 momentum: the signal yield is then extracted from the resulting $M(D^0)$ distribution. As there is no natural threshold in this case, we expect the yield to be relatively stable under variations of cuts, fit functions and so on.

VI. CONCLUSION

In summary, we have demonstrated the viability of this method of measuring the ratio of D^0 decay rates into $K_L^0\pi^0$ and $K_S^0\pi^0$. Our preliminary measurement of this ratio is

$$\frac{\mathcal{B}(D^0 \rightarrow K_L^0\pi^0)}{\mathcal{B}(D^0 \rightarrow K_S^0\pi^0)} = 0.88 \pm 0.09(\text{stat}) \pm 0.09(\text{syst});$$

expressing the result in terms of the rate asymmetry defined in [4], we find

$$\mathcal{A} \equiv \frac{\Gamma(D^0 \rightarrow K_S^0 \pi^0) - \Gamma(D^0 \rightarrow K_L^0 \pi^0)}{\Gamma(D^0 \rightarrow K_S^0 \pi^0) + \Gamma(D^0 \rightarrow K_L^0 \pi^0)} = 0.06 \pm 0.05(\text{stat}) \pm 0.05(\text{syst}),$$

which is consistent with unity. At the current level of precision we are therefore not able to place any strong constraint on the parameters of $D \rightarrow K\pi$ decays, and so the strong phase $\delta_{K\pi}$. However the statistical error will soon improve as more data is accumulated by the Belle detector; changes of technique to reduce the systematic error are also being actively studied.

Acknowledgments

We wish to thank the KEKB accelerator group for the excellent operation of the KEKB accelerator. We acknowledge support from the Ministry of Education, Culture, Sports, Science and Technology of Japan and the Japan Society for the Promotion of Science; the Australian Research Council and the Australian Department of Industry, Science and Resources; the Department of Science and Technology of India; the BK21 program of the Ministry of Education of Korea and the Center for High Energy Physics sponsored by the KOSEF; the Polish State Committee for Scientific Research under contract No.2P03B 17017; the Ministry of Science and Technology of Russian Federation; the National Science Council and the Ministry of Education of Taiwan; and the U.S. Department of Energy.

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